DEPARTMENT OF DEFENCE

DEFENCE SCIENCE & TECHNOLOGY ORGANISATION

DSTO

MEASURES OF EFFECTIVENESS FOR MARITIME AREA AIR DEFENCE

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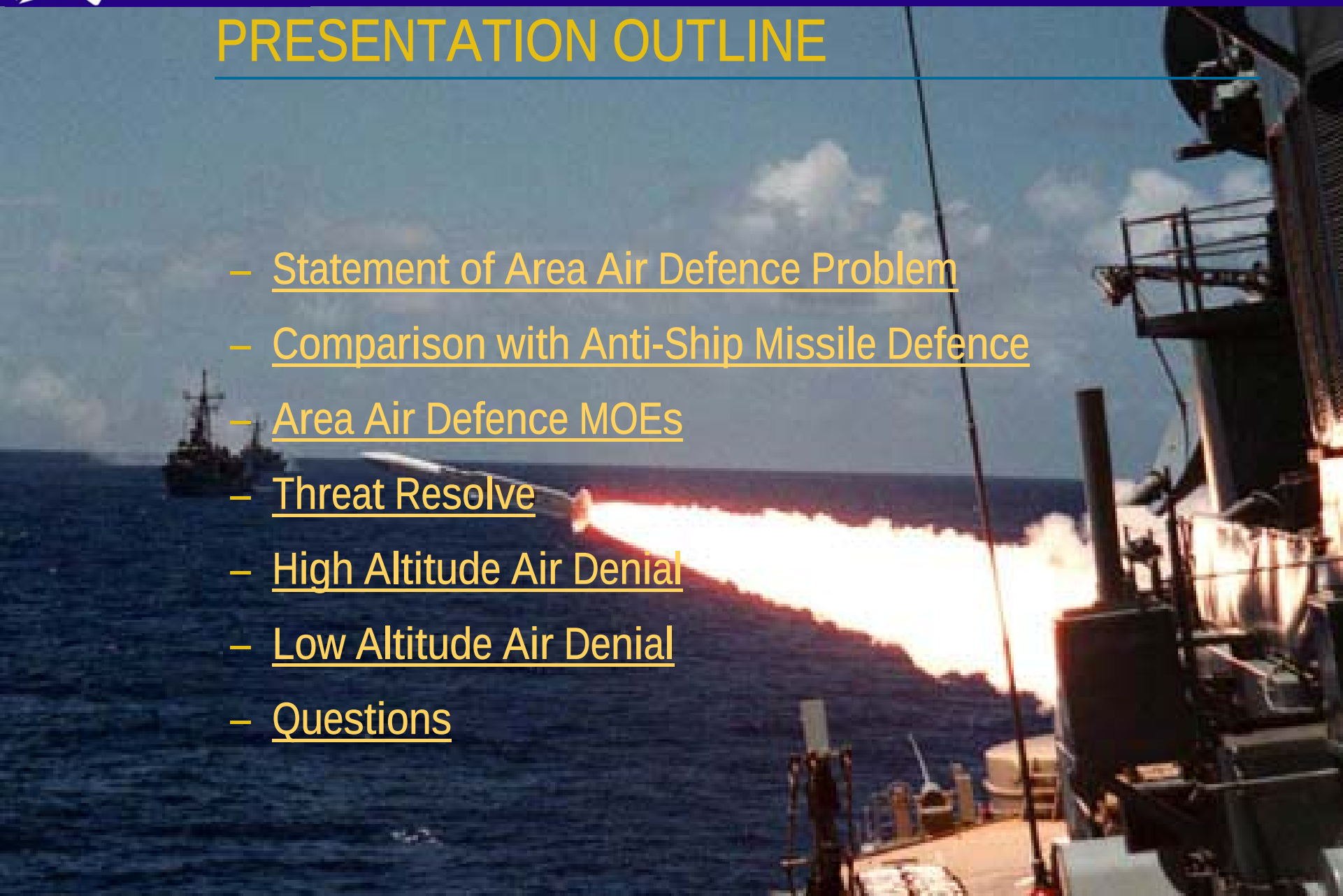
PRESENTATION OUTLINE



- Statement of Area Air Defence Problem
- Comparison with Anti-Ship Missile Defence
- Area Air Defence MOEs
- Threat Resolve
- High Altitude Air Denial
- Low Altitude Air Denial
- Questions

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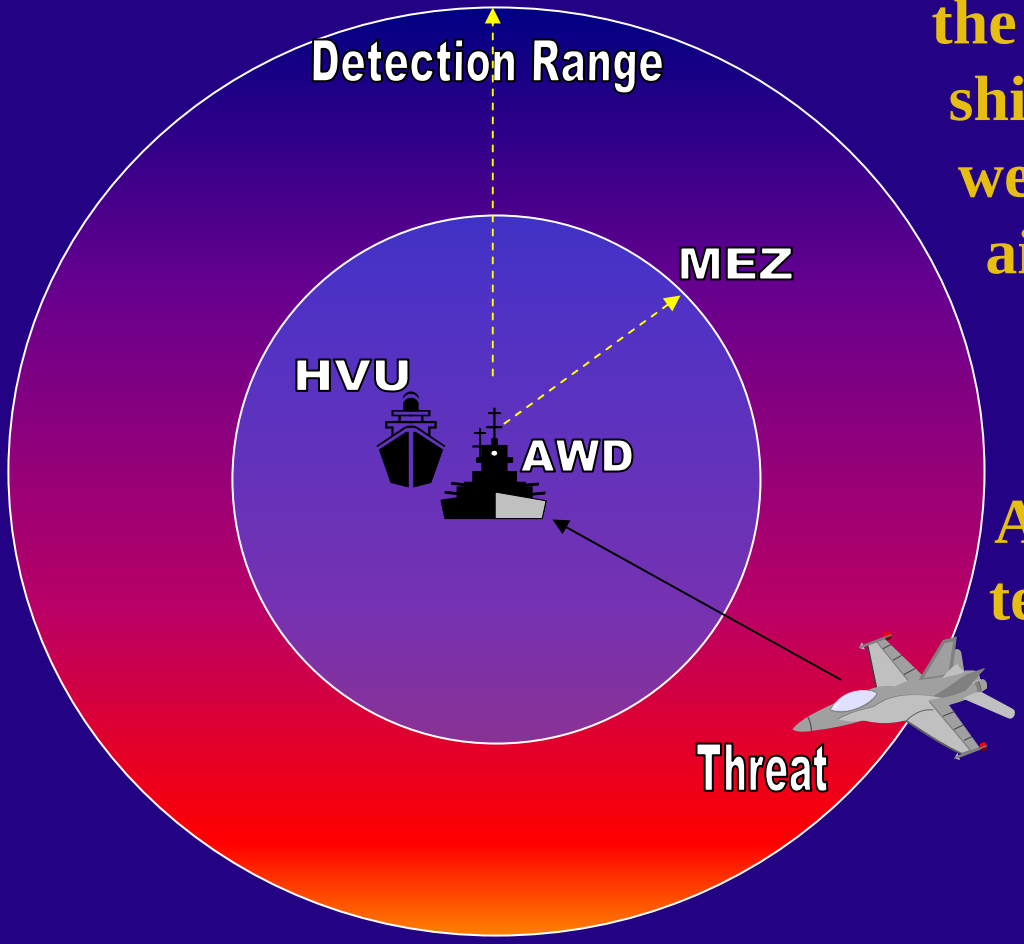
Area Air Defence (AAD)



Aim: Maritime AAD relates to the situation where a surface ship employs its sensors and weapons to deny a region of airspace to enemy aircraft.

Airspace denial is defined in terms of the risk the aircraft has to tolerate as it approaches the ship.

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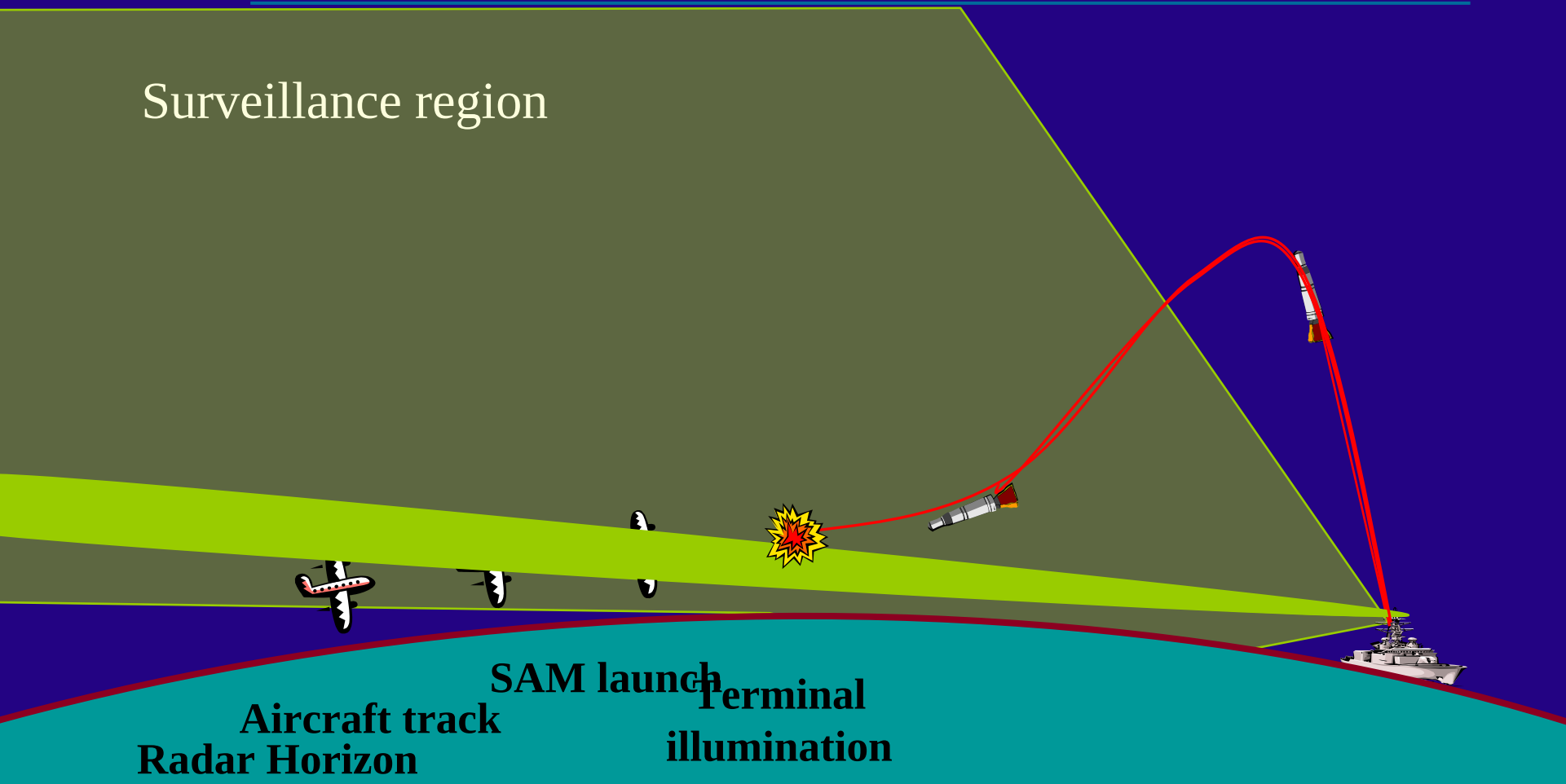
Semi-active SAM engagement sequence



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Comparison with ASMD

- AAD traditionally couched in terms of an ASMD scenario
- ASMD is a one-sided problem defined from the instant of ASM launch: namely, to defeat the incoming ASM before it reaches some keep out range from the ship
- Whereas ASMD may be likened to shooting the arrow, AAD is akin to shooting the archer

Comparison with ASMD

- Compared with ASMD, AAD is a more complex, two-sided problem:
  - Neither the ship nor the enemy aircraft are aware of how, when or if the other is going to react
  - MOEs need to be developed which do not depend on the response of either the ship or the aircraft

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AAD MEASURES OF EFFECTIVENESS (MOEs)

- Obvious MOE is the SAM's maximum intercept range:
  - Common measure of maximum range
  - Relevant to high level approach at long range
  - Can be compared with maximum range of ASM, etc…
- HOWEVER, the region around a ship within the intercept range is not necessarily denied to an enemy aircraft

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AAD MOEs Contd.

- Within the MEZ, the risk of being intercepted by a SAM launched by the ship will vary
- The boundaries of the transition from one risk level to another will depend, in part on the maximum intercept range, but also on other factors
- These boundaries serve to categorise the airspace surrounding the ship according to risk of intercept
- Their magnitudes provide MOEs for the AAD problem in the context of THREAT RESOLVE

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Threat Resolve

- Threat resolve is characterised by the risk that an attacking aircraft is willing to tolerate in approaching an AWD
- As a “first cut”, the air space surrounding the ship is divided into TWO coarse levels of risk to an aircraft:
  - DANGER ZONE (DZ)
  - SAFETY ZONE (SZ)
- DZ is defined as the region within which intercept is *possible*
- SZ is the region outside of the SAM engagement envelope where non-interception is guaranteed

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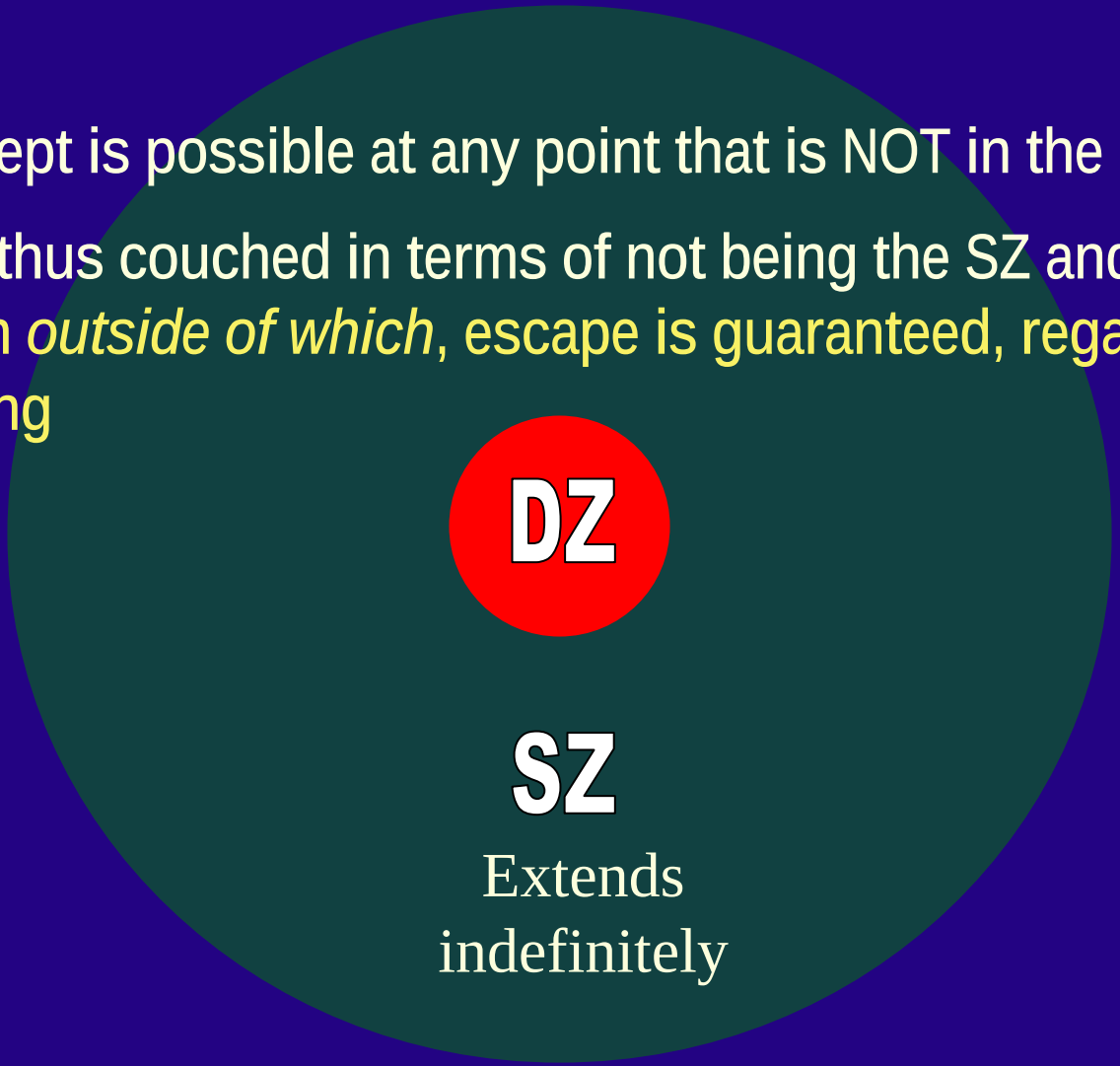
Threat Resolve

- Intercept is possible at any point that is NOT in the SZ
- DZ is thus couched in terms of not being the SZ and so is the region *outside of which*, escape is guaranteed, regardless of warning



Threat Resolve

The DZ may be further divided into three specific levels of risk of intercept to the aircraft. These are, in increasing order of risk:

Warning Zone (WZ) – the region within the SAM engagement envelope that allows an aircraft, following illumination, to escape prior to intercept. Escape is guaranteed with warning, but intercept is also possible if the warning is ignored.

No safety zone (NSZ) – the region within which the aircraft has the possibility of escape following SAM engagement, but at the same time can't guarantee its own safety. This applies regardless of warning.

No escape zone (NEZ) – the region within which the aircraft cannot escape following SAM engagement, regardless of warning.

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High Altitude Air Denial

- For a high altitude target (eg 30 kft), there will be no issue with radar horizon
- The categorisation of the airspace is thus 1D, with the boundaries of the SZ and the regions within the DZ corresponding to the three distinct levels of danger to the aircraft being determined by:
  - the SAM's capability (speed, maximum range)
  - the aircraft's capability (speed, turn times, reaction time) and
  - the ship's reaction time

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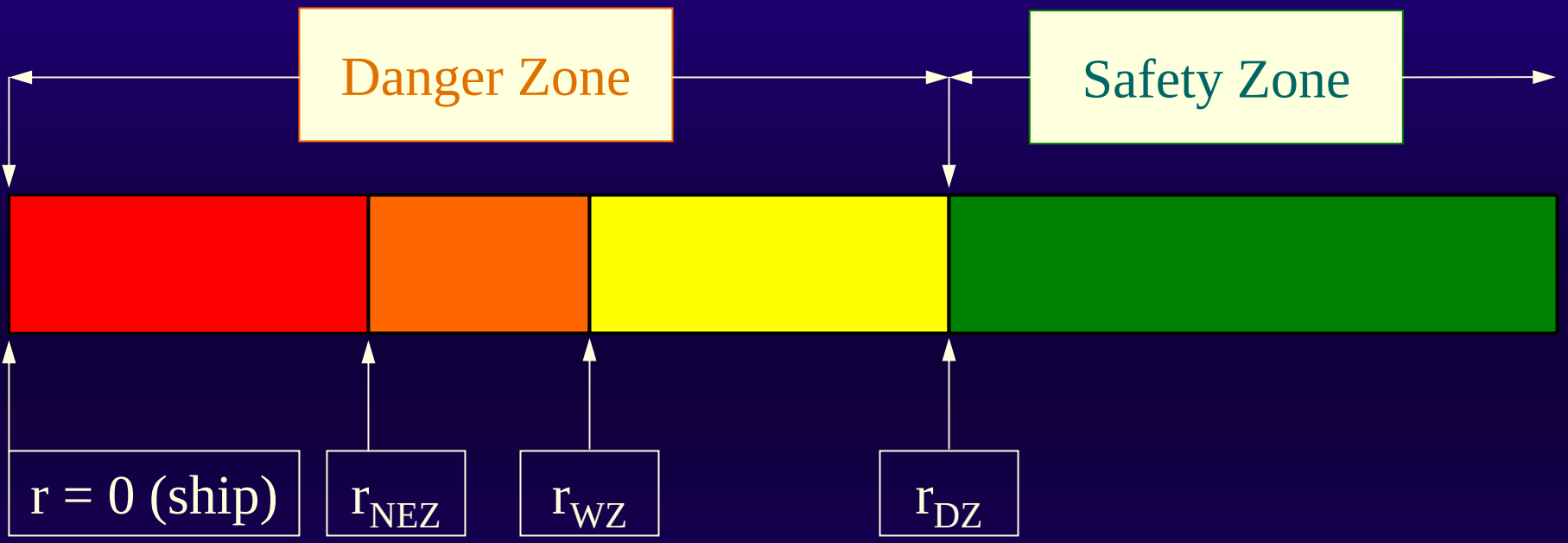
Categorisation of High Altitude Airspace



No Escape Zone - intercept guaranteed, regardless of warning

Warning Zone - escape guaranteed, with warning

No Safety Zone - no guarantee of escape, regardless of warning

Safety Zone - Guaranteed escape, regardless of warning

High Altitude Air Denial- NEZ Radius

- NEZ characterised by a radius r_{nez}
- Essentially a correction to the SAM engagement envelope, r_0, at the height of the aircraft
- Guaranteed intercept of aircraft flying at or within r_{nez} of ship, *regardless of warning time given to aircraft*
- Calculation is worst case from the point of view of the ship
- Allows for possibility that aircraft has turned before ship is aware of the manoeuvre

High Altitude Air Denial - NEZ Radius

- If the aircraft is assumed to have a constant speed v_{ac}, then an aircraft at r_{nez} at the time it decides to turn and flee will just be intercepted at r_0, where r_{nez} is given by

$$r_{NEZ} = r_0 - v_{ac}(tof + t_{ship} - t_{turn})$$

SAM flyout time Ship latency 180-deg turn time

- NEZ is thus a sub-level of the Danger Zone with a radius inside the SAM range envelope

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High Altitude Air Denial - DZ Boundaries

- Let the danger zone be characterised by a radius r_{dz}
- This is defined as $r > r_{dz} \Rightarrow r \in$ Safety Zone
- For $r < r_{dz}$, interception is possible. Guaranteed for $r < r_{nez}$
- Hence the region *between* the NEZ and the SZ constitutes a region where interception is possible, but not guaranteed
- It is next shown how this region may be divided further into the two distinct levels of air denial described previously:
  - (i) warning zone
  - (ii) no safety zone

High Altitude Air Denial - WZ Radius

- Suppose aircraft has a warning of $t_l \leq$ tof seconds of SAM launch before intercept at r_0 (eg., CWI from a ship's FCR)
- Again consider engagement at SAM range envelope, r_0
- A WZ radius, r_{WZ}, may be defined such that an aircraft at that distance from the ship will *just* be intercepted at r_0 if it immediately opens its range upon receiving the warning
- Consequently, an aircraft at any range $r > r_{WZ}$ will be guaranteed escape if it heeds the warning

High Altitude Air Denial - WZ Radius

- So the net "useful" amount of time available to the aircraft to flee the SAM from commencement of illumination to intercept at r_0 will be $t_I - t_D - t_{turn} - t_{acq}$. Hence the WZ radius will be given by:

$$r_{WZ} = r_0 - v_{ac}(t_I - t_D - t_{turn} - t_{acq})$$

Dither time Turn time Acquisition time

- Since $t_I \leq tof$, $r_{NEZ} \leq r_{WZ}$
- An aircraft at r_{WZ} will just be intercepted at the SAM's maximum range and so $r > r_{WZ} \Rightarrow$ guaranteed escape with warning

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High Altitude Air Denial - No Safety Zone

- But what about an an aircraft at a range greater than r_{NEZ} but less than r_{WZ}?
- Outside NEZ $\Rightarrow$ interception not guaranteed (regardless of warning)
- $r < r_{WZ} \Rightarrow$ escape with warning not guaranteed either
- Thus for an aircraft in the range $r_{NEZ} < r < r_{WZ}$ there is the possibility of escape, regardless of warning, but that escape cannot be guaranteed
- So in the NSZ, both intercept and escape are *possible*, but neither are guaranteed

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High Altitude Air Denial - DZ Radius

- To determine the boundary of the DZ, the warning terms in the equation for the WZ radius are set to zero

- Since the WZ determines the range beyond which escape is guaranteed *with warning*, then the zone so determined gives the range beyond which escape is guaranteed *regardless of warning* – ie., the boundary of the DZ

High Altitude Air Denial - DZ Radius

- If the illumination time is set to zero, then the acquisition time will also be zero and the DZ radius will thus be given by

$$r_{DZ} = r_0 + v_{ac}(t_D + t_{turn})$$

- Note that $r_{NEZ} \leq r_{WZ} \leq r_0 \leq r_{DZ}$. The outer boundary of the DZ is outside the SAM engagement envelope
- So an aircraft at a distance r_{DZ} from the ship at the decision to turn will just reach the SAM envelope after completing the turn in a time $t_D + t_{turn}$ (worst case from point of view of the aircraft)

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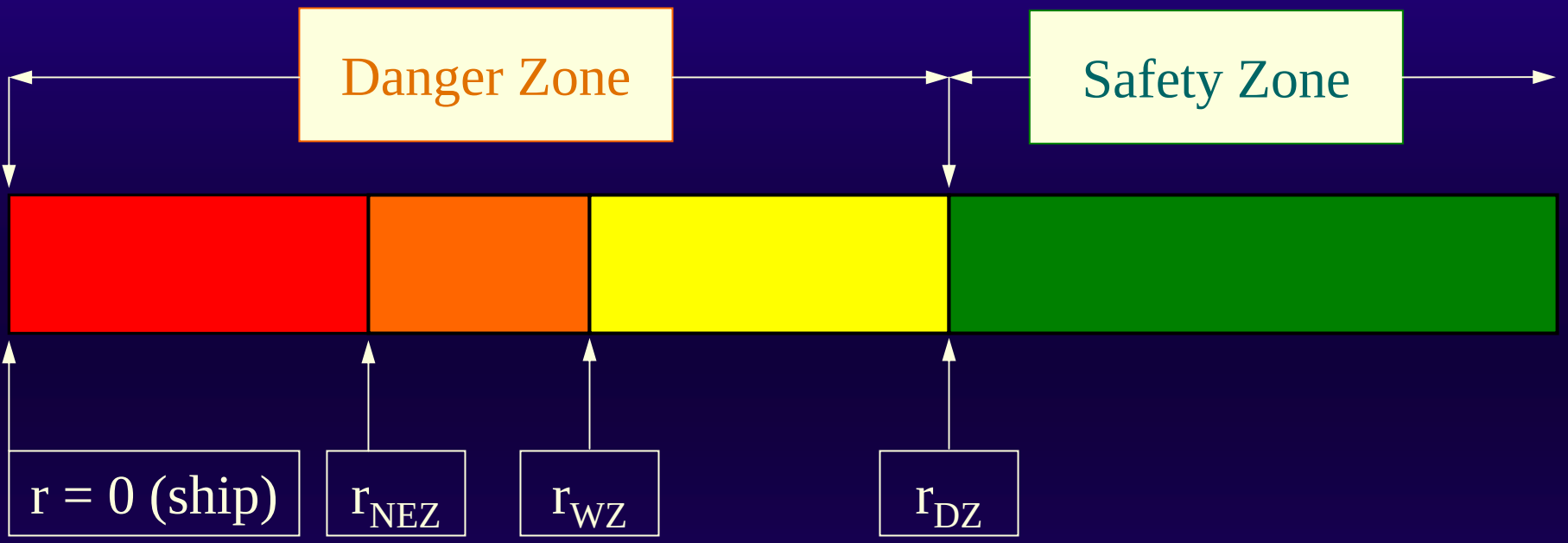
Categorisation of High Altitude Airspace



No Escape Zone - intercept guaranteed, regardless of warning

Warning Zone - escape guaranteed, with warning

No Safety Zone - no guarantee of escape, regardless of warning

Safety Zone - Guaranteed escape, regardless of warning

Low Altitude Air Denial

- Denial of airspace for aircraft escaping below the radar horizon

- Conceptually the same as high altitude denial, but with the added condition that aircraft can escape below the radar horizon

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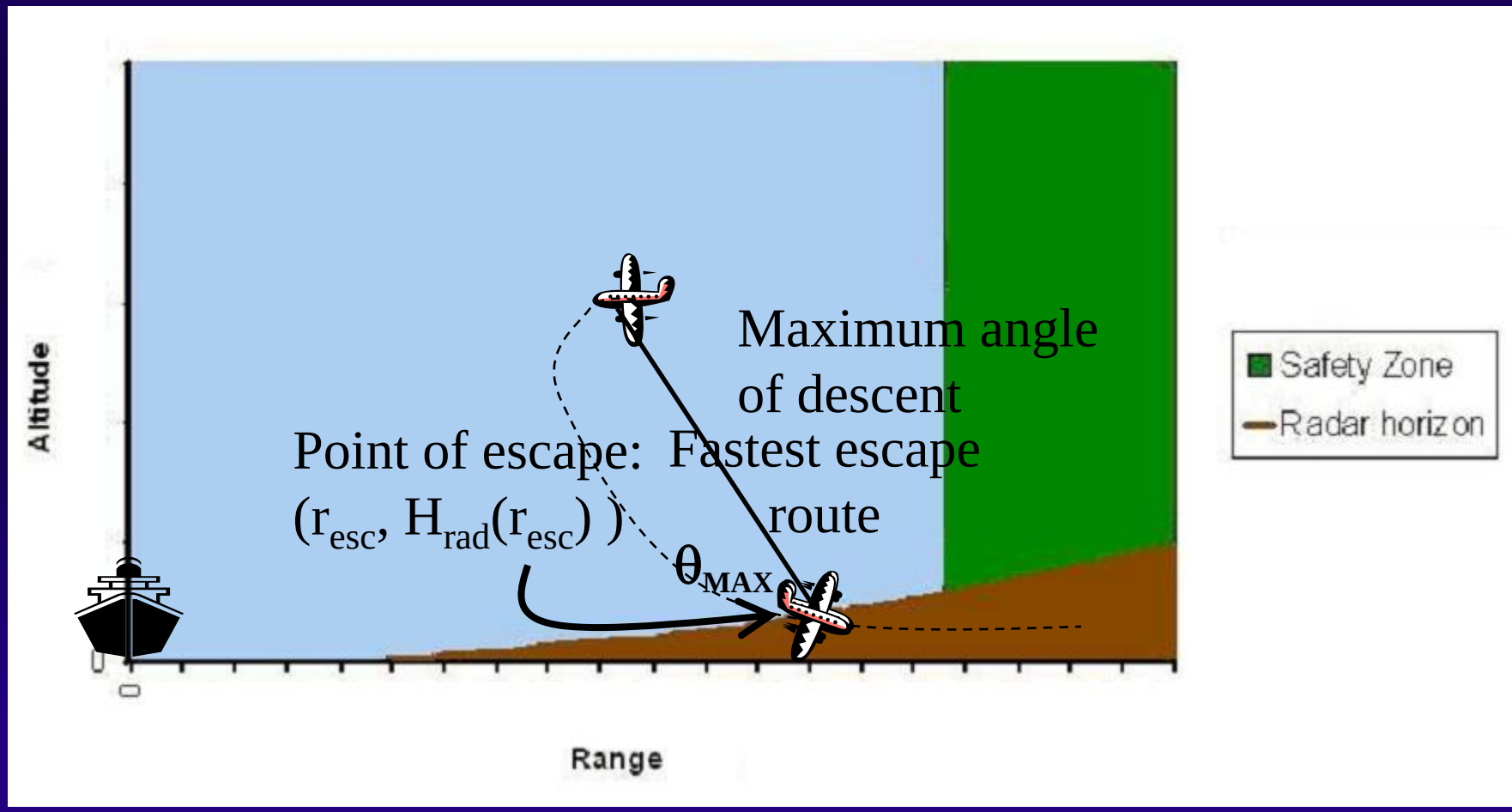
Low Altitude Air Denial – Aircraft perspective

- What is the risk to an aircraft at a given point in space?:



Low Altitude Air Denial

- The corresponding expression for the boundary between the Safety Zone and Danger Zone becomes:

$$r_{DZ}(h) = Min\left[H_{rad}^{-1}(h), r_0 + v_{ac}(t_D + t_{turn})\right]$$

- The boundary between the Warning Zone and No Safety Zone can be parameterised by the range of aircraft escape:

$$\begin{cases} h_{WZ}(r_{esc}) = H(r_{esc}) + T_{warning}\, v_{ac} \sin\theta_{MAX} \\ r_{WZ}(r_{esc}) = r_{esc} - T_{warning}\, v_{ac} \cos\theta_{MAX} \end{cases}$$

$$T_{warning} = t_I - t_{acq} - t_D - t_{turn}$$

where t_I and hence $T_{warning}$ may depend on r_{esc}:

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Low Altitude Air Denial

- Similarly the boundary between the No Safety Zone and No Escape Zone becomes:

$$\begin{cases} h_{NEZ}(r_{esc}) = H(r_{esc}) + T_{engage}(r_{esc})\, v_{ac} \sin\theta_{MAX} \\ r_{NEZ}(r_{esc}) = r_{esc} - T_{engage}(r_{esc})\, v_{ac} \cos\theta_{MAX} \end{cases}$$

$$T_{engage}(r_{esc}) = t_{flyout} + t_{ship} - t_{turn}$$

where t_{flyout} is a function of r_{esc}:

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Low Altitude Air Denial

- Note that significant operational complexities can be included in these calculations, such as:
  - Minimum aircraft flying altitudes,
  - Modified SAM kinematic horizons,
  - Support from Airborne Early Warning Aircraft,
  - Missiles with active seekers,
  - etc.

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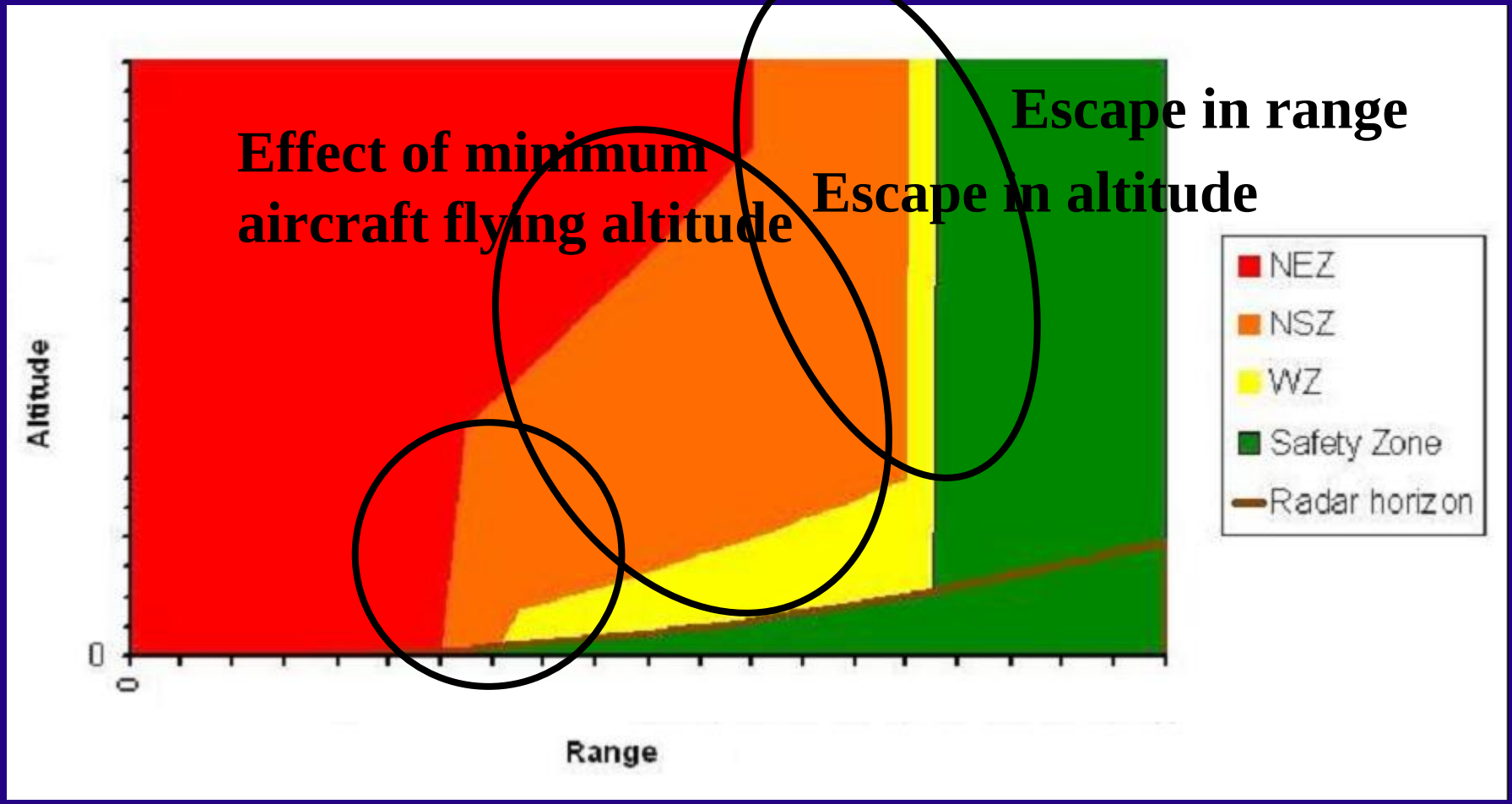
2-D Categorisation of Airspace



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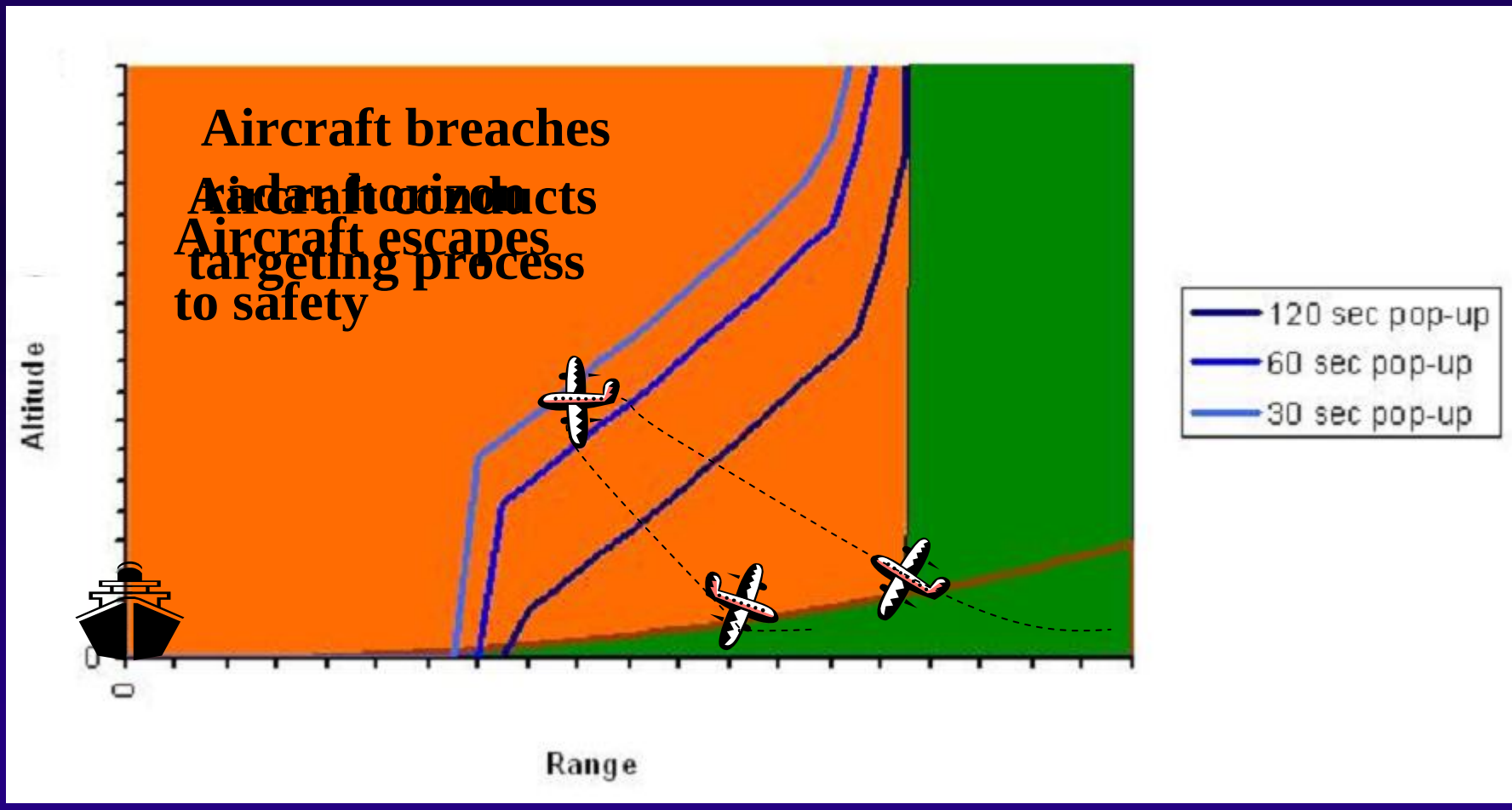
Low Altitude Air Denial – Ship's perspective



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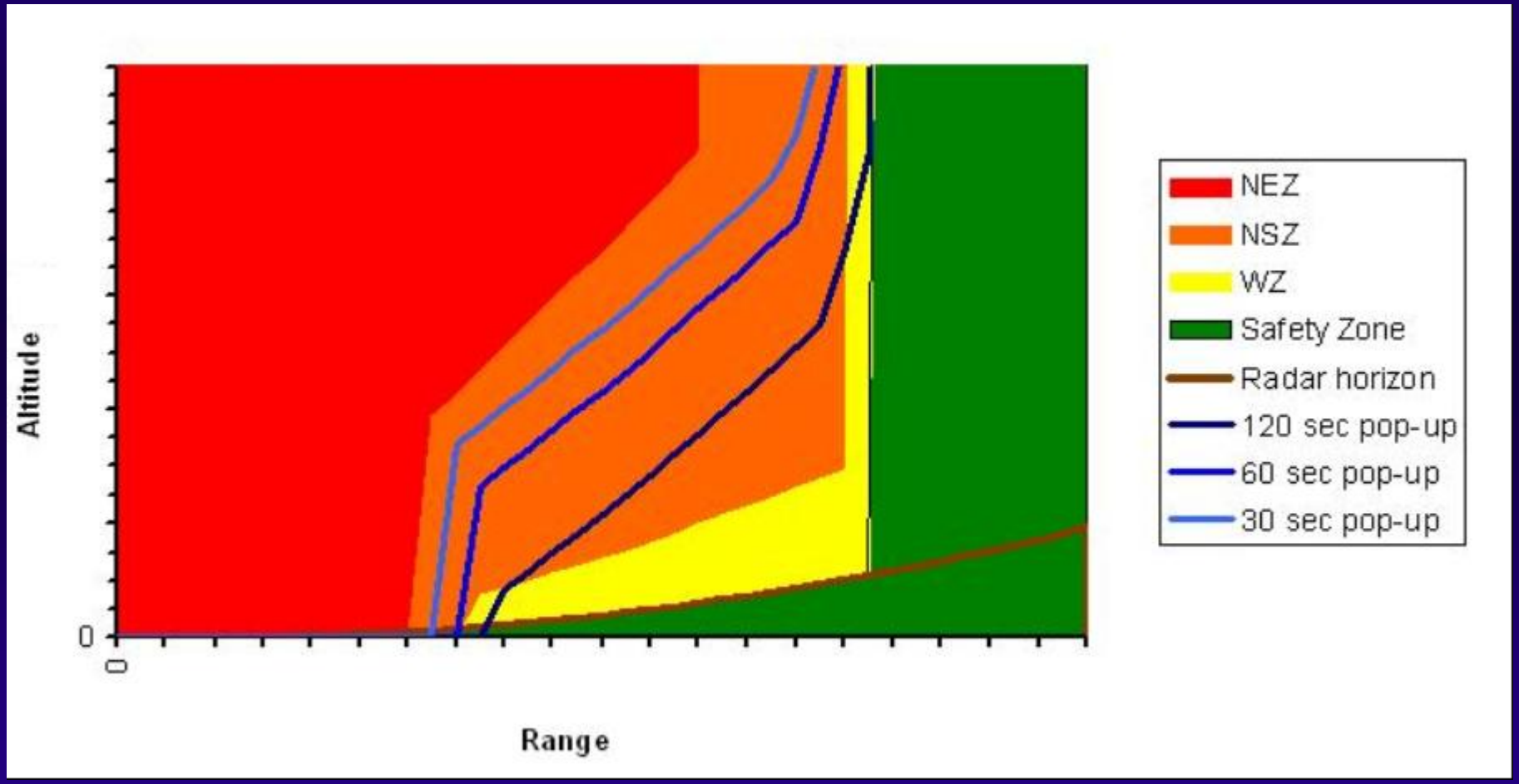
Low Altitude Air Denial - Combined perspective



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QUESTIONS

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1D AIRSPACE SCHEMATIC